

Internal Waves on the Shelf

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LONG-TERM GOAL

The long-range goal of this research is to understand the kinematics and dynamics of the internal wave field on the continental slope and shelf.

OBJECTIVES

The specific objectives of this project are focused on the continental shelf wave field and include: estimating the flux of each component of the internal wave field (tidal, inertial, continuum, high frequency), and producing a climatological description of shelf internal waves. The results will provide input to help modelers of coastal circulation improve the parameterization of mixing due to internal waves. Modelers of acoustic and optical propagation can also benefit from an improved description of the wave field.

APPROACH

Our approach to achieve these objectives is through the analysis of moored observations from: the Oregon shelf in 1999 (funding from NOPP), the Mid-Atlantic Bight during 1996 Primer/CM&O experiment (Boyd et al., 1997), and relevant archived data.

The method used to estimate energy flux varies with the component of the wave field. The tide, near-inertial, and high-frequency wave packets can be treated in a somewhat deterministic framework. The remaining broad-band continuum is more appropriately considered as a random sum of waves.

WORK COMPLETED

The initial effort has focused on the spectral continuum. A consistent framework has been developed for analyzing the wave field on the continental shelf and comparing with the deep-ocean Garrett-Munk (GM) spectral description (Levine, 2000). The application of this framework to observations is underway.

Data from the 1999 Oregon shelf moorings have been archived and analysis begun (Boyd et al., 2000).

RESULTS

The spectral framework used for the continental shelf internal wave field is patterned after the pioneering work of Garrett and Munk (1972). To generalize the Garrett-Munk (GM) spectrum to be useful in this application, several inconsistencies and ambiguities needed to be addressed to be able to compare internal wave fields at different latitudes, stratifications and water depths. A modified spectral formulation is presented in Levine (2000) that addresses three problems with the Garrett-Munk formulation: the interpretation of the scaling constants E (non-dimensional energy), b (vertical length scale), and N_0 (buoyancy frequency scale); the latitudinal dependence through the Coriolis parameter; and the treatment of vertical boundaries and turning points. Observations from different latitudes, buoyancy frequencies, and water depths, must be properly normalized to be able to make meaningful comparisons. The advantages of the modified spectrum are illustrated by comparing with observations from low latitude and the continental shelf.

Determining the three scaling parameters in the GM spectrum, E , b , and N_0 , from observations is ambiguous. Part of the problem is that only two of the parameters are independent in the spectral formulation (Desaubies 1976). Also, associating b and N_0 directly with $N(z)$ causes some confusion. In the modified formulation we choose two new, independent parameters: E_{ref} , a dimensional scale of energy / mass, and $D(\omega)$, a dimensional scale of the vertical waveguide. The determination of E_{ref} for the Mid-Atlantic Bight is compared with the deep ocean value in Figure 1.

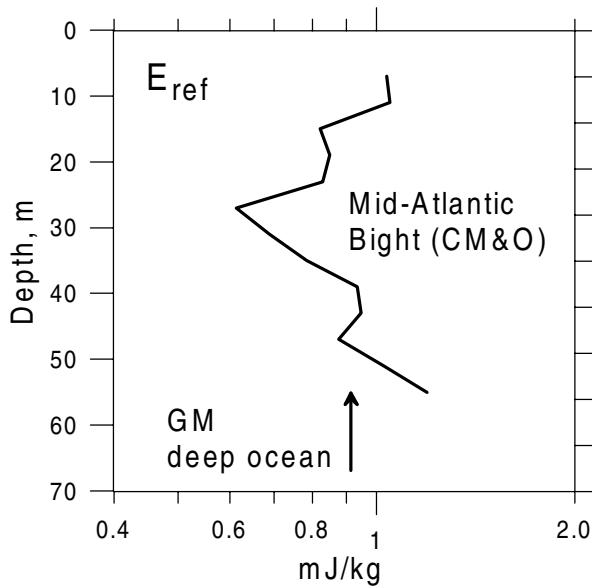


Figure 1. Vertical profile of E_{ref} determined from fitting the observed spectra measured during Primer / CM&O at different depths. These values are remarkably constant with depth and near the value typical of the deep ocean.

Another problem with the GM spectrum is the latitudinal dependence. In GM79 (Munk, 1981) the frequency spectral level scales as f — a dependence that is not observed. This failure is acknowledged in GM79, and it is suggested that this scaling by f be replaced by the value of f at 30°N (f_{30}). This fix, however, creates inconsistencies in the normalization of the spectrum which is determined by integrating from f to N . We suggest an alternate normalization, fixed to the level of the high frequency wave field, which removes the latitudinal dependence in a consistent manner.

In addition a new frequency spectral form is presented for frequencies less than the semidiurnal tidal frequency of 1/12 cph. This change is motivated by observations at low latitude that indicate a whiter frequency spectrum below the semidiurnal tidal band (Figure 2). There may be dynamical reasons for this change in spectral slope indicating the tide as an energy source to the internal wave continuum.

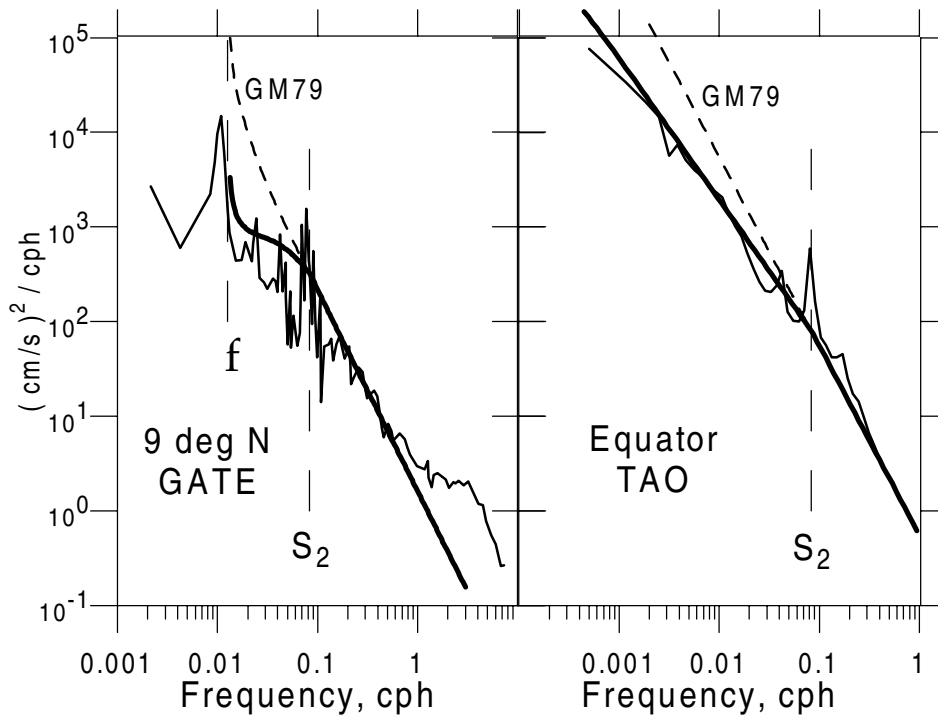


Figure 2. Moored spectra of horizontal velocity (thin solid line) observed from 9deg N (GATE) (Kase and Siedler, 1979) (left panel) and the equator (TAO) (McPhaden et al., 1999) (right panel) are compared with GM79 (dashed line) and the modified spectrum (bold solid line).

Regarding the treatment of the vertical dependence of the internal wave field, GM use a WKB approximation. This approach is useful as it provides an analytically convenient description of the vertical dependence. However, the effects of the boundaries and turning points are lost. We choose instead to include the effects of the boundaries and turning points while retaining the analytical advantages of the WKB approximation by defining WKB modes. This approach is especially useful in applying to the shallow ocean where the boundaries are important at even relatively high frequencies. The improvement in using WKB modes is illustrated by the vertical coherences (Figure 3).

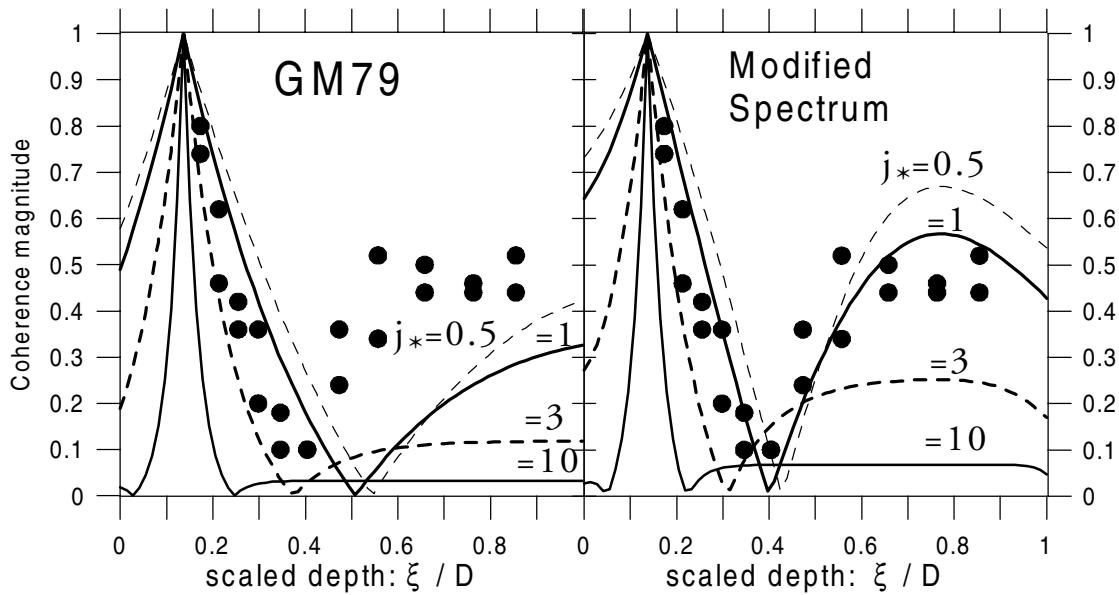


Figure 3. *Coherence at 0.5 cph between velocity at 51 m and other depths during the Primer / CM&O experiment (dots) are compared with GM79 (left panel) and the modified spectral form (right panel) for $j_* = 0.5, 1, 3, 10$. Depth is scaled with a coordinate stretched by N . The modified spectrum using WKB modes agrees much better than GM79.*

IMPACT/APPLICATIONS

Internal wave oscillations are a significant source of variability to acoustic and optical propagation. To understand and model these fluctuations, improved statistical descriptions are needed of the complete internal wave spectrum. Much of the existing modeling is based on the GM formulation, which may not be accurate on the continental slope and shelf.

TRANSITIONS

The analysis of the SAS Primer / CM&O data has been used by colleagues measuring and modeling acoustic propagation during the experiment (Williams, Henyey at APL/UW). Collaboration continues with Pleuddemann (WHOI) on incorporating their analysis of CM&O observations into an improved internal wave climatology.

RELATED PROJECTS

Three moorings were deployed across the continental shelf off Oregon in summer 1999, as part of a NOPP study of wind-driven coastal circulation. These extensive observations are being incorporated into the analysis.

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